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Composition of Non-Volatile Flavor Compounds in Fresh and Dried Sea Lettuce *(Ulva lactuca)*

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Abstract

Drying has the potential to alter the physical, chemical, and organoleptic characteristics of food materials. This study aims to identify the composition of non-volatile flavor compounds in fresh and dried sea lettuce (*Ulva lactuca*). The identification of non-volatile flavor compounds was conducted using amino acid profiling through High-Performance Liquid Chromatography (HPLC). The organoleptic characteristics, including appearance, aroma, texture, and taste of fresh and dried sea lettuce samples, were assessed through a simple descriptive test. The quantitative amino acid analysis data and the descriptive test results were analyzed using a comparative descriptive method. The findings revealed that both fresh and dried *Ulva lactuca* contain 17 types of amino acids, comprising 9 essential amino acids and 8 non-essential amino acids, which influence flavor characteristics. The descriptive test indicated that fresh *Ulva lactuca* is characterized by clean, shiny, and soft light green to dark green sheets with an elastic texture and a distinctive fresh seaweed aroma. In contrast, dried *Ulva lactuca* exhibited a yellowish-green color, a stiff and brittle texture, and a stronger salty taste with a slight umami sensation. These findings highlight the potential of *Ulva lactuca* as a versatile ingredient in food product development, particularly for enhancing flavor and nutritional value.

Keywords: *Non-volatile flavor compounds*; *Drying*; *Sea lettuce*.

Introduction

Indonesia, as a tropical maritime country, possesses biophysical characteristics that support the growth of various seaweed species. The diversity of seaweed in Indonesia includes 911 species out of the approximately 8,000 species found worldwide [1]. One seaweed species that grows naturally in Indonesian waters is *Ulva lactuca*. This species grows without cultivation in the waters around Lombok, Sumba, West Java, Bali, and Yogyakarta. The density of *Ulva lactuca* in the southern coastal areas of Yogyakarta reaches 21.25 individuals/m² at Ngandong Beach and 76.39 individuals/m² at Drini Beach [2].

Ulva lactuca, commonly known as sea lettuce, belongs to the green algae group and is classified as an edible seaweed (father seaweed). This seaweed is a nutrient-rich food source, containing sulfated polysaccharides, dietary fiber, protein, sugars, amino acids, polyunsaturated fatty acids, and phenolic compounds beneficial to human health [3]. *Ulva lactuca* has a salty and umami flavor with a distinctive seaweed aroma [4]. Its umami taste is attributed to the free amino acids, including 1.40% glutamic acid and 1.59% aspartic acid (dry weight), which are higher than the levels found in *Kappaphycus alvarezii* and *Acanthophora spicifera* [5]. In addition, *Ulva lactuca* can enhance food products by providing a crunchy texture and increasing fiber content [6]. It also contains chlorophyll at a concentration of 0.5608 mg/g, contributing to its appealing color in food applications [7].

Ulva lactuca can be utilized as a food ingredient either in the form of a fresh salad or through drying processes to create various other food products [8]. The drying process of Ulva lactuca results in products such as dried flakes, which are crispy seaweed fragments ready for consumption [9]. Additionally, drying can produce seaweed flour, which serves as a raw material for making chips [10].

Drying is a method used to reduce the water content of food materials by evaporating moisture with the aid of heat energy, airflow, or other drying techniques [11]. This process has the potential to alter the physical, chemical, and organoleptic characteristics of food. The reduced water content in food due to drying can significantly influence its appearance, texture, and flavor [12].

Flavor is a complex combination of sensory perceptions received by the human senses, particularly the perception of taste and aroma during the consumption of food or beverages [13]. Flavor plays a crucial role in determining consumer acceptance, influencing preference behavior and purchasing decisions for food products. Flavor compounds consist of volatile compounds that stimulate the sense of smell, affecting aroma, and non-volatile compounds that stimulate the sense of taste, influencing flavor [14]. Volatile compounds include ketones, aldehydes, esters, alcohols, nitrogen compounds, organic acids, furans, phenols, sulfur compounds, and hydrocarbons, while non-volatile compounds include inorganic ions, nucleotides, organic acids, and free amino acids [15].

Research on the composition of non-volatile flavor compounds in seaweed commodities remains scarce in Indonesia. In contrast, studies on non-volatile flavor compounds in seaweed have been extensively conducted in other countries. Examples of such research include studies on the effects of harvest time variations on non-volatile flavor-active compounds in *Porphyra haitanensis* and changes in the composition of non-volatile flavor-active compounds in *Kappaphycus* sp. before and after fermentation [16], [17].

The identification of non-volatile flavor compounds in a food commodity is essential as baseline data for mapping the flavor composition of food products [18]. Despite the growing interest in seaweed-based products, limited studies have explored the impact of drying on the composition of non-volatile flavor compounds in seaweed and how these changes influence its sensory characteristics. Several studies have shown that the drying process impacts the flavor compounds in seaweed [19], [20]. This gap in the literature hinders the development of seaweed-derived food ingredients, particularly in applications such as flavor enhancers and nutritional additives.

To address this, the present study investigates the non-volatile flavor compounds and sensory characteristics of fresh and dried *Ulva lactuca*. The analysis focuses on identifying amino acid profiles through High-Performance Liquid Chromatography (HPLC) and assessing sensory attributes, including appearance, aroma, texture, and taste. The findings aim to provide foundational data for further applications, including the development of innovative products like flavor powders.

Materials and methods

Materials

The instruments used in this study include a digital scale with a precision of 0.1 g for weighing samples, a tray as a sample container, an oven for sample drying, and packaging materials such as aluminum foil, cling wrap, and ziplock bags. A cool box was used to maintain sample quality during transportation, while label paper was used for identification purposes. The analysis was conducted using a High-Performance Liquid Chromatography (HPLC) instrument (SHIMADZU CMB 20A). The materials used included 2 kg of *Ulva lactuca*, as well as various chemical reagents such as ortho-phthalaldehyde (OPA), sodium hydroxide, boric acid, Brij-30 solution, 2-mercaptoethanol, standard amino acid solution, Na-EDTA, methanol, tetrahydrofuran, sodium acetate, and high-purity water.

Methods

The approach employed in this study is an exploratory method. The exploratory method is a research approach aimed at gathering preliminary information on a particular subject. This method was conducted through observations, which involved the collection of data related to the composition of non-volatile flavor compounds and the organoleptic characteristics of *Ulva lactuca*.

1) Sampling

The initial stage of this study involved the collection of *Ulva lactuca* samples from seaweed farmers at Ujung Genteng Beach, located in Sukabumi Regency, West Java, Indonesia. Renowned for its pristine coastal waters and diverse marine ecosystems, Ujung Genteng Beach provides an ideal environment for the growth of high-quality sea lettuce. The unique ecological conditions of this location contribute to the distinct flavor and nutrient profiles of *Ulva lactuca*. A total of 2 kg of *Ulva lactuca* was transported in fresh condition using plastic containers filled with a sufficient amount of seawater. The samples were then transported to the Fisheries Product Processing Laboratory at the Faculty of Fisheries and Marine Sciences, Universitas Padjadjaran.

2) Sample Preparation

The sample preparation was conducted at the Fishery Product Processing Laboratory, Faculty of Fisheries and Marine Science, Universitas Padjadjaran. *Ulva lactuca* was divided into two groups: fresh *Ulva lactuca* and *Ulva lactuca* intended for drying. The fresh *Ulva lactuca* was washed with seawater until clean, then drained for 10 minutes, after which 100 grams were weighed for organoleptic testing and identification of non-volatile flavor compounds. The *Ulva lactuca* to be dried was washed with seawater until clean, then drained for 10 minutes, and 500 grams were weighed for organoleptic testing and identification of non-volatile flavor compounds. After weighing, the samples were dried in an oven at 70°C for 1 hour and 30 minutes [21].

3) Packaging

Fresh and dried *Ulva lactuca* samples were packaged in aluminum foil, labeled, and wrapped in cling film before being placed in a zip-lock plastic bag. The packaged samples were then stored in a cool box containing ice and transported to the Integrated Laboratory of Bogor Agricultural University, with a travel time of 4 hours. Upon arrival at the laboratory, the samples were analyzed using High-Performance Liquid Chromatography (HPLC).

Research Parameters

1) Amino Acid Profile Analysis

The identification of the composition of non-volatile flavor compounds was carried out based on amino acid profile analysis using High-Performance Liquid Chromatography

(HPLC). The initial step in amino acid analysis involves dissolving the hydrolyzed sample in 10 mL of 0.01 N HCl, followed by filtration using Millipore paper. Afterward, a potassium borate buffer with a pH of 10.4 is added in a 1:1 ratio. A 5 µL aliquot of the sample is introduced into a clean, empty vial, to which 25 µL of OPA reagent is added, and the mixture is allowed to stand for 1 minute to complete the derivatization process. Subsequently, 5 µL of the sample is injected into the HPLC column, and the separation of all amino acids is monitored, which takes approximately 25 minutes.

2) Descriptive Test

The organoleptic characteristics, including appearance, aroma, texture, and taste of fresh and dried *Ulva lactuca* samples, were evaluated through a simple descriptive test. The simple descriptive test involved qualitatively describing the sensory characteristics, which encompassed appearance, aroma, texture, and taste, of both fresh and dried *Ulva lactuca* samples. The results of the sensory characteristic identification of fresh and dried *Ulva lactuca* were presented qualitatively.

Results and Discussion

1. Amino Acid Profile

The amino acid profile analysis using High-Performance Liquid Chromatography (HPLC) showed that both fresh and dried *Ulva lactuca* samples contain 17 types of amino acids, including 9 essential amino acids and 8 non-essential amino acids. The amino acid composition of fresh and dried *Ulva lactuca* is dominated by arginine (8006.33 mg/kg dry weight to 9044.14 mg/kg wet weight), glutamic acid (7473.01 mg/kg dry weight to 8430.76 mg/kg wet weight), and aspartic acid (6431.45 mg/kg dry weight to 7007.97 mg/kg wet weight). The findings of this study are consistent with several other studies that indicate *Ulva lactuca* contains 17 types of amino acids, predominantly glutamic acid, aspartic acid, and arginine [22]. The results of the amino acid profile analysis for both fresh and dried *Ulva lactuca* are presented in Table 1 and Figure 1.

Table 1. Amino Acids in Fresh and Dried *Ulva lactuca*

Amino Acids	Concentrations (mg/kg)		Taste Description
	Fresh *Ulva lactuca*	Dried *Ulva lactuca*	
Essential Amino Acids			
Arginine	9044.14	8006.33	Bitterness
Histidine	2580.58	2383.26	Bitterness
Threonine	3413.18	3259.90	Sweetness
Valine	3789.04	3514.02	Bitterness
Methionine	1031.74	776.48	Bitterness
Phenylalanine	4383.75	4155.27	Bitterness
Isoleucine	2993.67	2685.15	Bitterness
Leucine	4779.84	4397.26	Bitterness
Lysine	3124.22	2845.19	Bitterness
Non-Essential Amino Acids			
Aspartic acid	7007.97	6431.45	Umami
Glutamic acid	8430.76	7473.01	Umami
Serine	3590.36	3402.01	Sweetness
Glycine	3906.83	3781.84	Sweetness
Alanine	5812.07	5472.94	Sweetness
Tyrosine	1579.01	1465.81	Bitterness
Cysteine	215.45	85.05	Sweetness
Proline	2903.50	2620.75	Sweetness

The amino acid composition of seaweed is influenced by various factors, including species diversity, extraction methods, processing techniques, seasonal variations, and environmental conditions [21], [23], [24]. The seaweed cultivation site at Ujung Genteng Beach is characterized by its diverse ecological conditions, which support the growth of *Ulva lactuca*. On average, approximately 15 to 20 tons of *Ulva lactuca* can be harvested annually from this area, with the peak harvest season typically occurring during the dry season (April to October), when seaweed growth is optimal due to calm waters and stable weather conditions. The site's ecological condition is favorable, with stable water quality and nutrient levels. While localized anthropogenic pressures, such as coastal development and pollution, may occasionally affect the ecosystem, the area remains relatively unaffected by significant human activities, supporting sustainable seaweed production and enhancing its amino acid profile.

This study shows that the drying process of *Ulva lactuca* leads to a reduction in amino acid concentrations. This decrease is attributed to protein or amino acid degradation, which is influenced by complex factors such as temperature, enzyme activity, and moisture content during the drying process [25]. The majority of the amino acid concentration decrease during drying is related to Maillard reactions and oxidation processes involving amino acids, sugars, and oxygen [26]. This decline is caused by the interaction between the terminal amino group and the carbonyl group of reducing sugars, resulting in conjugated compounds or Maillard reaction products [27]. Furthermore, prolonged drying times can accelerate the decomposition of heat-sensitive amino acids [26].

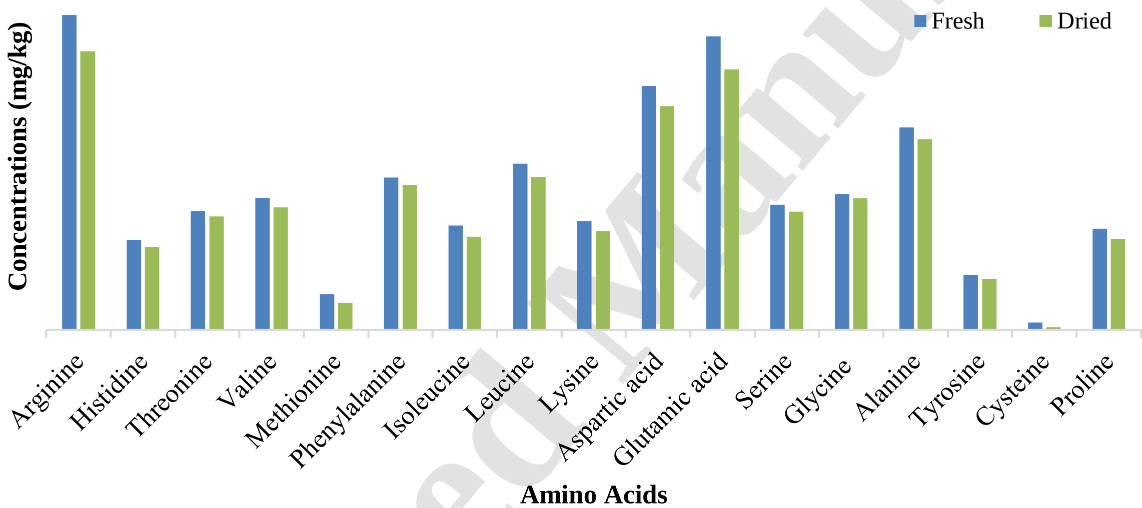

Figure 1. Profile of amino acids of fresh and dried *Ulva lactuca*.

The alteration in amino acid concentrations of *Ulva lactuca* during the drying process has significant implications for its contribution to flavor profiles. Drying induces biochemical changes that can enhance or diminish specific amino acid levels[19]. These changes influence the sensory attributes of *Ulva lactuca*-based food products, affecting their palatability and consumer acceptance.

The concentrations of arginine in fresh and dried *Ulva lactuca* were 9044.14 mg/kg of fresh weight and 8006.33 mg/kg of dry weight, respectively. Arginine is a basic amino acid that plays a role in protein formation and serves as a precursor in the synthesis of other compounds, such as creatine, agmatine, urea, polyamines, proline, glutamate, and nitric oxide [28]. Arginine imparts a bitter taste with a threshold range of 50 mg/100 mL [15], [29].

Arginine is considered a conditionally essential amino acid because the human body requires additional arginine from food under certain conditions, such as during growth in infants, pregnancy, significant immune system challenges, or after burn injuries [30]. Arginine plays a role in various biological processes, including protein synthesis, immune response, the urea cycle, and nitric oxide production [31].

The histidine detected in fresh and dried *Ulva lactuca* was 2580.58 mg/kg of fresh weight and 2383.26 mg/kg of dry weight, respectively. Histidine is an essential amino acid with an imidazole ring in its side chain, giving it aromatic properties [32]. Histidine contributes to the bitter taste of food with a threshold range of 20 mg/100 mL [29]. It plays a crucial role in maintaining body pH balance, binding metal ions, combating reactive oxygen and nitrogen species, supporting red blood cell formation, and acting as a neurotransmitter [33]. Histamine exhibits dual properties: on one hand, it can trigger inflammatory responses contributing to pathological processes, such as allergies, while on the other, it also plays a role in maintaining bodily functions, such as regulating intestinal function [34].

The concentration of threonine in fresh and dried *Ulva lactuca* was 3413.18 mg/kg of fresh weight and 3259.90 mg/kg of dry weight, respectively. Threonine is an essential amino acid containing a unique methyl group, as its side chain can form hydrogen bonds and interact non-polarly [35]. Threonine imparts a sweet taste to food with a threshold range of 260 mg/100 mL [29]. It plays a vital role in bone formation, maintaining overall health, supporting the immune system, liver, and nervous system, preserving body proteins, and participating in digestive functions and fat metabolism [36]. Threonine consumption can support intestinal health and function by preserving intestinal histological structure, mucus production, intestinal wall permeability, enzyme activity, and growth [37].

The valine content in fresh and dried *Ulva lactuca* was 3789.04 mg/kg fresh weight and 3514.02 mg/kg dry weight, respectively. Valine is an essential amino acid with a hydrophobic side chain [38], [39]. It contributes to the bitter taste with a threshold range of 40 mg/100 mL [29]. Valine plays a crucial role in protein metabolism, regulating cell activity, and maintaining the balance of the muscular and skeletal systems [40]. Daily consumption of valine can enhance focus, cognitive flexibility, and psychosocial functions [41].

The methionine content detected in fresh and dried *Ulva lactuca* was 1031.74 mg/kg fresh weight and 776.48 mg/kg dry weight, respectively. Methionine is an essential amino acid containing a sulfur atom [42]. Methionine can impart a bitter taste to food with a threshold range of 30 mg/100 mL [29]. Methionine plays a role in regulating various body functions, including protein synthesis, lipid metabolism, liver health, calming tense nerves, and preventing the accumulation of fat in the liver and arteries [43], [44]. The sulfur content in methionine can function as a natural antioxidant for the body [45].

The concentrations of phenylalanine in fresh and dried *Ulva lactuca* were 4383.75 mg/kg of fresh weight and 4155.27 mg/kg of dry weight, respectively. Phenylalanine is an essential amino acid that contains a phenyl group [46]. It imparts a bitter taste to food, with a threshold range of 90 mg/100 mL [15], [29]. Phenylalanine plays a role in regulating mood and supporting the balance of neural and cognitive functions [47]. It stimulates the release of cholecystokinin hormone in plasma and increases pressure on the pylorus, which regulates energy intake and controls blood glucose levels [48].

The isoleucine content in fresh and dried *Ulva lactuca* was 2993.67 mg/kg of fresh weight and 2685.15 mg/kg of dry weight, respectively. Isoleucine is an essential branched-chain amino acid that is both glucogenic and ketogenic [49]. Isoleucine also contributes a bitter taste, with a threshold range of 90 mg/100 mL [15], [29]. It is involved in protein synthesis, supports growth, maintains nitrogen balance, builds body tissues, and generates energy [50]. Isoleucine enhances glucose consumption and utilization in the body by increasing glucose transport activity in the intestines and muscles [51].

Leucine detected in fresh and dried *Ulva lactuca* was 4779.84 mg/kg of fresh weight and 4397.26 mg/kg of dry weight, respectively. Leucine is a branched-chain essential amino acid that helps enhance protein storage in the body [52]. Leucine can impart a bitter taste to food, with a threshold range of 190 mg/100 mL [29]. Leucine consumption has a positive effect on body composition, such as reducing body fat and increasing muscle mass without affecting body weight [15]. It also regulates various cellular processes, including protein synthesis, tissue regeneration, and metabolism in the human body [53].

The concentration of lysine in fresh and dried *Ulva lactuca* was 3124.22 mg/kg of fresh weight and 2845.19 mg/kg of dry weight, respectively. Lysine is an essential amino acid that exists in two enantiomeric forms, L-lysine and D-lysine [54]. Lysine contributes to a bitter taste with a threshold range of 50 mg/100 mL [15], [29]. Lysine plays a key role in maintaining bone health by reducing calcium excretion in urine, enhancing calcium absorption, strengthening bones, and stimulating osteoblast activity [55]. It is also crucial for collagen formation, tissue repair, and the production of enzymes, antibodies, and hormones [56], [57].

The content of aspartic acid in fresh and dried *Ulva lactuca* is 7007.97 mg/kg of fresh weight and 6431.45 mg/kg of dry weight, respectively. Aspartic acid is a non-essential amino acid that contains a carboxyl group in its side chain, making it acidic [58]. Aspartic acid imparts an umami taste to food, with a threshold range of 100 mg/100 mL [29]. This amino acid plays a crucial role in various bodily processes, such as urea synthesis, the purine-nucleotide cycle (PNC), the malate-aspartate shuttle (MAS), gluconeogenesis, and neurotransmission [59]. It supports energy production, reduces fatigue, aids in RNA and DNA synthesis, and facilitates liver detoxification, thus offering a wide range of clinical benefits [60].

Glutamic acid detected in fresh and dried *Ulva lactuca* amounts to 8430.76 mg/kg of fresh weight and 7473.01 mg/kg of dry weight, respectively. Glutamic acid is a non-essential amino acid with a side chain consisting of a carboxyl group and a carboxylate ion [58]. It can provide an umami flavor to food with a threshold range of 30 mg/100 mL [29]. This compound is a key neurotransmitter that plays a significant role in driving brain activity, enhancing brain function, and promoting mental activity [61]. In vitro and in vivo studies show that glutamic acid is an essential nutrient for lymphocyte proliferation, cytokine production, phagocytic activity, macrophage secretion, and the ability of neutrophils to kill bacteria [62].

The concentration of serine in fresh and dried *Ulva lactuca* was 3590.36 mg/kg fresh weight and 3402.01 mg/kg dry weight, respectively. Serine is a non-essential amino acid that is polar due to the presence of a hydroxyl group at the end of its side chain [63]. It contributes to the sweet taste in foods, with a threshold range of 150 mg/100 mL [29]. This compound is essential for cell growth and development [64]. Serine plays a crucial role in the synthesis of glycine, the folate and methionine cycles, the formation of sulfur-containing amino acids, and neurotransmission processes [63].

The glycine content in fresh and dried *Ulva lactuca* was 3906.83 mg/kg fresh weight and 3781.84 mg/kg dry weight, respectively. Glycine is a non-essential amino acid with a side chain consisting of a single hydrogen atom [65]. It imparts a sweet taste to foods, with a threshold range of 130 mg/100 mL [29]. This compound acts as a neurotransmitter in the central nervous system and performs various functions, such as antioxidant, anti-inflammatory, cryoprotective, and immunomodulatory roles in nerve tissue and the body [66]. Glycine can regulate inflammatory responses by acting on various target cells throughout the body [67].

The concentration of alanine detected in fresh and dried *Ulva lactuca* was 5812.07 mg/kg fresh weight and 5472.94 mg/kg dry weight, respectively. Alanine is a non-essential amino acid with a core structure that forms the backbone of peptides, enabling the formation of α-helix and β-sheet structures [68]. Alanine contributes to the sweet taste of food, with a threshold range of 260 mg/100 mL [29]. This compound can regenerate antioxidants in tissues and improve kidney and liver functions [69]. Furthermore, alanine serves as a precursor for glucose formation in the liver [70].

The concentration of tyrosine in fresh and dried *Ulva lactuca* was 1579.01 mg/kg fresh weight and 1465.81 mg/kg dry weight, respectively. Tyrosine is a non-essential amino acid with a hydroxyl group attached to its side chain [71]. Tyrosine imparts a bitter taste to food, with a threshold range of 0.7 mg/mL [15]. This compound plays a crucial role as a precursor in the formation of monoamine neurotransmitters in the brain, such as dopamine, adrenaline, and noradrenaline, as well as hormones like thyroxine and triiodothyronine [72]. Tyrosine also participates in electron and proton donation during enzymatic reactions, making it a frequent component of active sites in enzymes like galactose oxidase, ribonucleotide reductase, and cytochrome c oxidase [73].

The cysteine detected in fresh and dried *Ulva lactuca* was 215.45 mg/kg fresh weight and 85.05 mg/kg dry weight, respectively. Cysteine levels decrease significantly during drying due to its sensitivity to oxidation and thermal degradation, as the drying process can promote the formation of disulfide bonds or other oxidative reactions that deplete free cysteine [74]. Cysteine is a non-essential amino acid that contains a sulfhydryl group, which allows it to function as a reducing agent in redox reactions [75]. Cysteine contributes to the sweetness in food with a threshold range of 0.225 mg/mL [15]. This compound plays a crucial role in protein synthesis, the formation of the antioxidant glutathione, and the production of the non-proteinogenic amino acid taurine [76]. Cysteine is also capable of scavenging free radicals, particularly oxygen radicals [77].

The proline content in fresh and dried *Ulva lactuca* was 2903.50 mg/kg fresh weight and 2620.75 mg/kg dry weight, respectively. Proline is a non-essential amino acid that is unique due to its side chain, which forms a ring connected to the backbone of the molecule, making it highly rigid [15]. Proline can impart a sweet taste to food, with a threshold range of 300 mg/100 mL [15], [29]. The metabolism of this compound plays an essential role in various biological processes, such as cell signaling, stress protection, and energy production. Proline acts as a protector against stress by serving as an osmolyte, shielding against oxidative stress, assisting protein folding, stabilizing membranes, and scavenging reactive oxygen species [78].

2. Descriptive Analysis Test

The results of the descriptive analysis test revealed differences in sensory characteristics between fresh and dried *Ulva lactuca*. Thermal processing caused changes in the appearance, aroma, texture, and taste of *Ulva lactuca*. The descriptive analysis data for fresh and dried *Ulva lactuca* are presented in Table 2.

Table 2. Observational Results of the Descriptive Analysis of Fresh and Dried *Ulva lactuca*

No.	Parameters	Observation Results	
		Fresh *Ulva lactuca*	**Dried *Ulva lactuca***
1	Appearance	Clean, transparent, glossy, sheet-shaped with a length of 3–19 cm and a width of 0.5–3 cm, and light green to dark green in color	Clean, wrinkled, sheet-shaped, and yellowish-green in color
2	Aroma	Fresh, characteristic of seaweed	Specific to the type of seaweed
3	Texture	Soft and elastic, not easily broken between the stem and branches (thallus)	Dry and stiff, easily broken between the stem and branches (thallus)
4	Taste	Salty with a slight umami sensation	Stronger salty taste with a slight umami sensation

The moisture content of fresh *Ulva lactuca* was approximately 85% of its wet weight. Following drying, the moisture content decreased substantially to approximately 15%, leading to a marked alteration in its physical appearance [20]. The appearance is the first impression received by the visual senses in assessing the characteristics of seaweed. Fresh *Ulva lactuca* has a clean, transparent, glossy appearance, with a sheet-like form measuring 3 cm to 19 cm in length and 0.5 cm to 3 cm in width, and is light to dark green in color. The green color of the seaweed is attributed to the presence of chlorophyll a and chlorophyll b within the chloroplasts [74]. Dried *Ulva lactuca* has a clean appearance with a shriveled sheet-like form and a yellow-green color. The shriveled form of *Ulva lactuca* is a result of reduced water content during the drying process, which causes structural changes in the seaweed [75]. The color change to yellow-green is caused by the Maillard reaction that occurs during the drying process [76]. The appearances of fresh and dried *Ulva lactuca* are presented in Figure 1.

Figure 2. Appearance of Fresh and Dried *Ulva lactuca* (a) Fresh *Ulva lactuca*; (b) Dried *Ulva lactuca.*

The aroma of seaweed is a form of sensory response to stimuli from volatile compounds [79]. Fresh *Ulva lactuca* has a characteristic fresh seaweed scent. The aroma of *Ulva lactuca* is herbal with subtle earthy or mushroom-like notes [80]. Dried *Ulva lactuca* samples emit a distinct aroma typical of seaweed. The drying process causes changes in aroma due to the formation and evaporation of volatile compounds. Thermal decomposition of carbohydrates, fats, amino acids, and Maillard reactions during drying leads to the formation of volatile compounds such as hydrocarbons and alcohols [81]. Additionally, the drying process can cause the volatilization of components such as ammonia and low-boiling-point compounds, resulting in a decrease in the concentration of volatile components [82].

Texture is an important factor in the acceptance of both fresh and processed seaweed as food [83]. Fresh *Ulva lactuca* has a soft and elastic texture, which makes it difficult to break between the stems and branches (thallus). This is consistent with the observation that fresh *Ulva lactuca* resembles cartilage, being thin and slightly flexible [80]. Drying processes result in dried *Ulva lactuca* samples with a dry, rigid texture that easily breaks between the stems and branches (thallus). The drying process alters the physical and chemical properties of the seaweed due to the reduction in moisture content, which affects the brittleness and texture of *Ulva lactuca* [84].

Taste is another important factor influencing the acceptance of seaweed-based food products [80]. Fresh *Ulva lactuca* has a salty taste with a subtle umami sensation, characteristic of this particular seaweed species. The salty taste in seaweed comes from the presence of inorganic ions such as K, Na, and Cl [85]. In contrast, dried *Ulva lactuca* has a stronger salty taste and a slight umami sensation. This is due to the reduction in moisture content during the drying process, which intensifies the natural salty flavor of *Ulva lactuca*. Consequently, drying *Ulva lactuca* is recommended for food preservation as it enhances flavor and prolongs shelf life by decreasing moisture content. Nonetheless, it is essential to carefully control the drying conditions to avoid nutrient loss and preserve the desired taste qualities.

The drying process significantly influences the taste profile of *Ulva lactuca*, as it alters the concentration and composition of its non-volatile flavor compounds. These findings have substantial implications for the food science and industry sectors, where dried *Ulva lactuca* could serve as a natural flavor enhancer in soups, snacks, and seasonings, particularly in plant-based based diets [9]. Additionally, the amino acids preserved or concentrated during drying, such as glutamic acid, aspartic acid, and arginine, offer notable health benefits [86]. Expanding the utilization of dried *Ulva lactuca* in functional foods and nutritional supplements could bridge the gap between sensory appeal and health promotion, offering innovative solutions for consumer demands.

Conclusions

Based on the discussion, it can be concluded that both fresh and dried *Ulva lactuca* contain 17 types of amino acids that contribute to its flavor profile. Two amino acids that impart an umami taste are glutamic acid and aspartic acid. Six amino acids responsible for sweetness include threonine, serine, glycine, alanine, cysteine, and proline. Meanwhile, nine amino acids that provide bitterness are arginine, histidine, valine, methionine, phenylalanine, isoleucine, leucine, lysine, and tyrosine. Descriptive testing reveals that fresh *Ulva lactuca* has a clean, transparent, glossy appearance, with sheet-like structures ranging in length from 3 cm to 19 cm and in width from 0.5 cm to 3 cm. The color varies from light to dark green, and it has a distinct fresh seaweed aroma. The texture is soft, elastic, and not easily broken between the stalk and branches (thallus). The taste is salty with a subtle umami sensation. In contrast, dried *Ulva lactuca* appears clean, with a shriveled sheet-like form and a yellowish-green color. It has a specific seaweed aroma and a dry, brittle texture that easily breaks between the stalk and branches (thallus). The salty taste is more pronounced, accompanied by a slight umami sensation.

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